AN APPRAISAL OF CERTAIN SOURCES

OF ENVIRONMENTAL VARIATION

IN THE PRODUCTIVITY OF YORKSHIRE SOWS

ABSTRACT

A study of the records of 616 Yorkshire litters farrowed over a 20 year period in the University of Alberta's herd indicated that litter performance was not associated with differences in weight changes of the sow during gestation or with gestation length. Age, breeding weight and litter order were highly correlated and were mutually dependent in their effect on litter performance.

A Least Square analysis indicated that increases in litter size at weaning were strongly associated with increases in weight loss of the sow during lactation; while breeding weight of the sow, classed by 40 pound intervals into nine classes, enhanced litter size at birth up to the sixth class (mean weight of 432 pounds) after which a slight decline occured. Differences were largest in the early classes. Litter size at weaning exhibited little variation over most of the central breeding weight classes, but dropped sharply in the first class (mean weight of 232 pounds) and in the last class (mean weight of 574 pounds). Litter weight at weaning increased to the third breeding weight class (mean weight of 314 pounds) after which time the variation present reflected differences in litter size.

The relationships between the various traits of the sow are discussed.

THE UNIVERSITY OF ALBERTA

AN APPRAISAL OF CERTAIN SOURCES OF ENVIRONMENTAL VARIATION IN THE PRODUCTIVITY OF YORKSHIRE SOWS

A DISSERTATION

SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

FACULTY OF AGRICULTURE

DEPARTMENT OF ANIMAL SCIENCE

by

GORDON HERBERT BOWMAN

EDMONTON, ALBERTA,

OCTOBER, 1956

ACKNOWLEDGEMENTS

The author wishes to thank Dr. L.W. McElroy, Head of the Department of Animal Science, for making available the data used in this study, and to acknowledge the advice and assistance of Dr. J.P. Bowland, Associate Professor of Animal Husbandry, in the preparation of this manuscript.

The author is indebted to Dr. H.T. Fredeen, Animal Husbandman, Experimental Farm, Lacombe, for initiating the project, for being instrumental in having certain phases of the analytical work conducted on I.B.M. and electronic machines, and for providing guidance and counsel throughout the course of the project.

This study was made possible in part by a National Research Council Bursary awarded during the year 1953-54.

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INTRODUCTION

The wide variation in sow productivity as measured by the performance of her litter constitutes a major problem to the breeder who is attempting, through selection, to improve his swine herd. A knowledge of the factors contributing to the observed variation would aid materially in evaluating performance traits that might be used in a selection program.

Variation consists of two major components. The first originates because of environmental differences under which the animals are raised, and is called environmental variation. The second is an expression of real differences between individuals, and is called genetic variation. It represents the portion of variation that is heritable, and provides the avenue through which improvement is made by selection. The extent by which improvement will be forthcoming will depend on the amount of genetic variation present and the degree to which these hereditary effects can be recognized in the presence of the masking effects of environment. Environmental variation, by causing errors in judgement of genotypic merit impedes the rate of genetic progress.

Two approaches may be employed by animal breeders in coping with environmental variation. One is to provide for statistical control by measuring the effects of known factors and adjusting observations accordingly. The second is to eliminate such variation entirely, in so far as this is possible, through the use of environmental and biological control.

Of the two approaches the latter is perhaps the most desirable; however, it is frequently not practical or feasible. Hence, the adjustment of data by the application of existing knowledge is frequently the only effective means of providing environmental control.

The objective of this study was to evaluate certain environmental factors with which sow productivity is associated.

The productivity of sows is regarded here as a measure of the performance of their litters up to and including weaning. Environmental traits of the sow considered were breeding weight, age at farrowing, litter order, length of gestation, and weight changes during gestation and lactation. External environmental influences include year and season. Performance traits of the litter consist of total number born, number born alive, number weaned, litter birth weight of living pigs, litter weaning weight and average pig weights at birth and weaning.

2. LITERATURE REVIEW

The variation attributable to non-genetic factors provides an indication of the importance of environmental control and indicates the specific type of program that will most likely be effective in achieving overall progress. The study of variation as such is the study of trends. Trends are reported as simple averages and in the form of more complex statistics. Important contributions in this field of swine breeding have been forthcoming from numerous sources. Of particular significance are reports by Lush and Molln (15) and Korkman (13), each of which involves studies on over 5,000 litters.

Age of Sow at Successive Litters. - Of the various factors shown to influence litter performance, age of sow probably has been studied most extensively.

Age of sow classed by six-month intervals is usually used in United States and litter order in Europe in classifying data to study the effect of age of sow at successive litters. In the past, farrowing in the United States has usually been restricted to early spring and early fall. Therefore, age increments of six months are likely to represent successive litters. Hence, the two methods may be reconciled by considering this to be so and making comparisons on the basis of litter order. Kozeluka (14) reported correlations of .94, .95, and .96 between these two traits for three different groups of European sows.

The results of several investigations in the United States (15, 20, 22) and Europe (7, 13, 16, 18, 19) indicating the relationship between litter order (or age of sow) and the number of pigs living at birth and at three weeks or later are summarized in table 1.

Salient features of these data are as follows:

(1) Litter size at birth rises rapidly from the first to the third litter, followed by a gradual rise to a peak at the fifth to eighth litter, after which a gradual decline occurs.

(2) Litter size at three weeks or later rises to a peak usually between the third to fifth litters followed by a decline. In American data this trend is spasmodic while in European data it is abrupt between the first and second litters and gradual thereafter.

(3) The somewhat earlier peak in birth numbers compared with weaning number reflects increased postnatal mortality with increasing age of sow.

While the trends are similar between these two regions, in the studies reported, the magnitude of the results differ markedly. European sows performed better than those from the United States in number of pigs alive at three weeks or later by an average of approximately two pigs for all classes of sows. The superior performance was a combination of larger litter size at birth and of reduced mortality during lactation. This may reflect the effect of breeds, since in United States the pigs considered were dominated by the lard breeds while those represented in the European data were largely bacon breeds. However, management and the extent of "personalized" care are undoubtedly of vast importance. While modifications in management and breed development may alter the absolute value of these traits, the trends are likely to remain similar.

The extent to which these data represent the inherent capacity of performance at various age levels may be biased because in general a larger number of litters are represented by sows in the younger age groups. This reflects culling of sows before they reach the older ages. Presumably inferior litter

Table 1 - Data from various investigations showing the number of pigs born alive and living at three weeks or later as influenced by age of dam or litter order.[1]

	United States						European Countries							
Litter trait	Age of sow	Lush and Molln (15)	Russell (20)	Shelby (22)	Average	Mortality %	Litter order	Ellinger (7)	Korkman (13)	Menzies-Kitchin (16)	Olbryet (18)	Olsen (19)	Average	Mortality %
Pigs born alive (Av. No.)	1.0	7.9	8.0	9.4	8.43		1	9.4	9.7	8.6	9.5	9.3	9.30	
	1.5	8.5	8.3	9.9	8.90		2	10.0	10.3	9.8	10.7	10.7	10.30	
	2.0	9.5	9.4	11.1	10.00		3	11.5	10.9	10.1	11.4	11.7	11.12	
	2.5	9.5	8.3	11.6	9.80		4	12.0	11.0	10.5	11.8	12.0	11.46	
	3.0	9.9	9.8	11.9	10.53		5	12.0	11.0	10.5	11.9	12.5	11.58	
	3.5	9.9	9.5	11.6	10.33		6	12.2	11.0	10.9	11.7	12.8	11.70	
	4.0	9.6	9.3	11.7	10.20		7	12.1	10.8	11.4	11.3	12.5	11.62	
	4.5	9.8	9.6		9.70		8	12.3	10.7	11.2	11.2	12.2	11.52	
	5.0	9.4	9.4		9.40		9	11.9	10.7	10.4	10.8	12.0	11.16	
	5.5	9.0	8.0		8.50		10	11.7	10.6	10.4	10.1		10.70	
No. of litters		7352	1150	1560				1340	5410	1290	1560	981		
Age		8 Wk.	10 Wk.	8 Wk.					3 Wk.	6 Wk.	8 Wk.	8 Wk.		
Pigs alive at three weeks or later (Av. No.)	1.0	5.1	5.6	7.1	5.93	29.6	1		8.5	7.2	7.8	7.2	7.68	17.3
	1.5	5.5	5.6	7.3	6.13	31.1	2		8.8	8.2	8.7	8.7	8.60	17.1
	2.0	6.0	6.5	7.8	6.77	32.3	3		9.1	8.2	8.9	9.1	8.82	20.0
	2.5	5.7	5.5	7.4	6.20	36.7	4		8.8	8.3	8.9	9.3	8.82	22.1
	3.0	5.5	6.3	8.1	6.63	37.0	5		8.9	8.4	9.0	8.9	8.80	23.3
	3.5	5.7	5.8	7.6	6.37	38.4	6		8.5	8.6	8.6	8.7	8.60	25.9
	4.0	5.1	5.1	7.8	6.00	41.2	7		8.5	8.9	8.4	8.6	8.60	25.2
	4.5	5.2	5.6		5.40	44.3	8		8.1	8.9	8.0	8.5	8.38	26.0
	5.0	4.9	5.2		5.05	46.3	9		8.4	8.4	7.6	8.5	8.22	25.1
	5.5	5.8	4.7		5.25	38.2	10		7.8	8.5	6.8		7.70	25.7

[1]The averages and percent mortality give equal weight to each investigation.

size at birth and weaning may be a factor in such culling. In this regard Ellinger (7) and Olbryct (18) included in their studies (table 1) only sows which had farrowed ten litters. Their results, however, do not differ widely from those in which all sows were included.

Hammond (9) reported that the number of corpora lutea on the ovaries of 18 gilts was 14.3 $\pm$ 0.39 and of nine mature sows 19.8 $\pm$ 1.26; thus providing a possible basis for the improved performance of sows in the middle-aged groups.

Sinclair and Syrotuck (23) reported that average birth weights of pigs increased progressively from 2.45 to 2.69 pounds as age of sow increased from one to five years. This is in general agreement with Carmichael and Rice (3) who found average birth weights of pigs from gilts and six-year old sows to be 2.44 and 3.00 pounds respectively. Total litter weight at birth was to a large extent a function of litter size. Average pig weights at three weeks was shown by Korkman (13) to increase very slightly from 5.37 to 5.67 kilograms (11.9 to 12.5 pounds) between the first and second litters and thereafter tend to remain constant, falling slightly in litter orders of ten and over. Sinclair and Syrotuck (23) noted a stronger trend in which average pig weights at weaning increased progressively from 27.6 pounds to 35.2 pounds, as age of sow increased from one to four years, and dropped to 33.4 pounds for sows who were five years of age. Lush and Molln (15) found that total litter weight at weaning increased sharply from an average of 139 pounds to 183 pounds between the first and third litters and thereafter declined to 134 pounds by the ninth litter. In examining their results it would appear that changes in total litter weights were confounded with changes in litter size, but never-

theless the sharp increase between the first and third litters was greater than can be attributed to size of litter alone.

From the foregoing review it is clear that certain general trends exist between age of sow and litter performance. As age of sow increases the nature of the pattern exhibited is one of improved performance in litter size, litter weight, and average pig weights at birth and up to at least weaning, to a peak in performance followed by a gradual decline.

The age of the sow at which maximum performance is attained is characteristic of the individual litter trait being considered. Birth numbers usually reach a peak at the fifth to eighth litter; weaning numbers at the third to fifth litter; total litter weights and average pig weights at birth at the fifth or sixth litters and total litter weights and average pig weights at weaning at the second to fourth litters.

The importance of these trends can perhaps be assessed by determining the percentage of the total variance in litter performance associated with differences in age of sow. Hetzer <u>et al</u>.(10) attributed 10.7, 4.9, and 6.0 percent of the total variance in litter size at birth, at 28 days, and at 70 days to differences in the ages of dams. Olbryct (18) found age of dam to account for 8.7 and 10.3 percent of the total variance in numbers born and weaned; Nordskog <u>et al</u>.(17) reported age of dam accounted for 7.6, 18.8 and 21.6 percent of the variance of litter weights at birth, 21 days and 56 days respectively; while litter order was shown by Korkman (13) to account for 3.9, 1.6 and 3.6 percent of the total variance respectively in the number of pigs born alive, alive at three weeks, and litter weight at three weeks.

The variance in litter performance partitioned to age of sow is low, particularly in view of the clear trends that are evident. This undoubtedly reflects the high inter-age variability in litter performance that is so characteristic of swine production.

<u>Age of Female at First Farrowing</u>. - Studies of the influence of age of female at first farrowing have been of two types. One method has measured the influence of age on both first and subsequent litter performance, while the second has been restricted to measurements of the first litter.

Keith (11) found litter size at birth was 7.30 and 7.67 pigs respectively for gilts farrowing at 12 and 18 months. Maximum performance of gilts farrowing at 12 months was not reached until the sixth litter, while those farrowing at 18 months attained maximum performance at the third litter. He felt this indicated that sows farrowing at later ages would have superior life performance. Hence, within limits, the older the age at first farrow the greater is lifetime productivity. On the other hand Olbryct (18) in studying three groups of gilts farrowing at average ages of 352, 404 and 513 days observed litter sizes at birth to be 8.04, 8.66 and 9.11 pigs respectively. The influence of age of gilt at first farrow was such that those farrowing their first litters at the greater age reached their peak of fertility at an earlier litter sequence, but at approximately the same age. From this, Olbryct concluded litter size to be influenced more by age of female than by litter sequence and the net result from breeding gilts at a greater age was to reduce lifetime productivity.

The lack of agreement between Olbryct and Keith may reflect either breed differences or sampling errors since Keith studied 636 litters of American breeds in 28 classes, while Olbryct considered 1560 litters of the Large White breed in 30 classes.

Korkman (13) reported a regression of 0.24 on litter size from gilts farrowing at monthly intervals from eight to twenty-three months; while Stewart (25) found that as age of dam increased from nine to 15 months a quadratic regression gave a significantly better fit than a linear regression. He concluded a curvilinear relationship existed between age at first farrow and litter size. The effect of age was much more important before 12 months; and by 15 months it ceased to be a factor.

Squiers _et al._ (24) reported that for each increment of ten days in age of gilt at conception the number of embryos present at the 25th day of gestation increased by an average of 0.50. This increase was reported to be a combination of 0.35 more ova shed and 0.15 fewer embryo lost. These data would then suggest, that the superior litter size associated with an increase in age of gilt at first farrow is a joint function of an increase in ovulation rate and a decrease in embryo mortality.

An indication of the importance of variation in litter size caused by age at first farrow is given by Stewart (25) who was able to attribute 3.2 percent of the total variance present to this source.

Weight Changes of the Sow During Gestation and Lactation. - Weights and weight changes of sows undoubtedly vary because of genetic factors; however, they probably are also highly influenced by environment, particularly because weight frequently reflects the condition of an animal, and because within herd treatment often varies. For example, it is common practice for swine producers to feed younger and thinner sows more abundantly than older and fatter sows.

Donald and Fleming (6) attempted without success to increase birth weights and numbers by liberal feeding of the dam during gestation. Zeller et al.(28) reported that sows bred at a lighter weight gained at a higher daily rate and farrowed larger litters than those bred at heavier weights; while Stewart (25) noted that gilts of a heavier weight at breeding gained more during gestation and farrowed slightly larger litters.

Schafer (21) found an increased weight loss during nursing to be associated with heavier litter weights at four weeks, but to bear no relationship to litter weights at eight weeks. Subsequent performance was best on gilts whose loss in weight during nursing was average. On the other hand Zeller et al. (28) reported weight changes during lactation to be highly associated with litter weights at weaning, and hypothesized that a high relationship existed between loss of weight and milk production in sows and an increased litter weight at weaning. Therefore they suggested that caution should be exercised in culling sows at weaning on the basis of thinness since such sows, if healthy, could represent superior producing stock.

Weights and weight changes of sows have not been studied extensively. The foregoing review does not establish any decisive pattern. Because body weight and changes in body weight are traits that fluctuate widely between herds and breeds of swine they may well deserve more attention than they have received.

Internal Litter Relationships. - Average birth weights of pigs were shown by Weaver and Bogart (27) to decrease from 3.1 to 2.6 pounds as litter size increased from four to thirteen pigs. The decrease was most apparent after

farrowing numbers exceeded ten. Average weaning weights exhibited no general trend as weaned litter size increased. The authors concluded that unless litter size was exceptionally large, no relationship existed between birth numbers and average birth weights. On the other hand Deakin and Fraser (5) reported a slight decrease in the average weights of pigs at three weeks as litter size increased from four to twelve pigs. This finding is supported by Wawra (26) who found average pig weights at four weeks of age to decrease from 8.4 to 5.8 kilograms (18.5 to 12.8 pounds) as litter size increased from six to twelve pigs and by Menzies-Kitchin (16) who reported average pig weights at weaning decreased from 21.9 to 17.6 pounds as weaned litter numbers increased from four to twelve pigs.

Weaver and Bogart (27) found the maximum number of pigs were weaned from sows farrowing ten to thirteen pigs. Mortality however, increased from 1.5 percent in litters of four pigs at birth to 30 to 40 percent in litters of ten to thirteen pigs at birth. Korkman (13) likewise found mortality to increase with larger numbers at birth. His data indicated that 12 pigs born alive would provide maximum weaning numbers. Weaver and Bogart also observed that stillbirths did not occur until the number of pigs born exceeded eight. Thereafter, as litter size increased from nine to thirteen pigs the proportion of stillbirths increased from 2.4 to 20.0 percent respectively.

It would appear that the size of the litter can modify average performance. As an environmental source of variation this trait has not been studied extensively. Perhaps the evaluation of sow productivity on the basis of total litter weight at weaning, as is common in United States, has detracted from such studies.

Season. - Bywaters (2) found season to account for seven percent of the total variance in weaning weights of pigs, with fall pigs averaging 5.6 pounds heavier than spring pigs. Hetzer et al. (10) was able to attribute only one percent of the total variance in litter size at 70 days to season; and Baker et al. (1) reported that season accounted for 0.8, 0.7, and 0.3 percent of the total variance in numbers alive at birth, 21 days and 56 days respectively. Korkman (13) partitioned 0.7, 0.9 and 2.5 percent of the total variance for numbers alive at birth, 21 days and litter weight at birth to season.

From these results it would appear that seasonal differences contribute little to variations in litter performance. The superiority of spring versus fall was not consistent, indicating that type of management and housing within seasons may be important.

Herd. - Herd differences on eight experiment and college farms were shown by Lush andMolln (15) to account for 5.0, 4.0, and 10.0 percent of the total variance in numbers born alive, numbers weaned, and litter weaning weight respectively. Korkman (13), from a study on eight farms attributed 2.1, 2.5, and 1.5 percent of the total variance in number of pigs alive at birth, number at three weeks, and litter weight at three weeks respectively to differences between herds. Both Lush and Molln, and Korkman comment that some of the herd differences may have been of genetic origin.

3. THE DATA

A. Source

A record of the sow and her litter has been kept for the swine herd, Department of Animal Science, University of Alberta, for over 30 years. The data collected are taken in a routine manner by the herdsman in charge and recorded in a herd book designed for the purpose. The data that had accumulated for the period 1934 - 1953 were made available for this study.

Only litters of registered Yorkshire parentage were included. The data were further restricted by discarding all litters on which information was not complete and by discarding litters in which either the sow or the litter up to weaning age had been involved in nutritional studies. These considerations led to the rejection of 166 litters scattered throughout most years as well as the entire data for 1948, the spring of 1949, and the fall of 1950.

The data remaining consisted of 616 litters farrowed by 214 sows and sired by 40 boars. Contributions of individual sows varied from one to ten litters. The maximum number of litters sired by a particular boar was 55 while the minimum was two. Of the 40 boars represented, 17 sired less than 10 litters and 13 more than 20, while only 5 sired more than 30 litters.

The origin of the data by year of farrow and month of farrow within season is presented in table 2. The majority of the spring litters were farrowed in February, March and April, while fall litters were generally farrowed in July, August and September.

The discarding of certain data may have altered the magnitude of certain litter performance traits in relation to the true values of the population since such data tended to represent poorer performing litters. This was

TABLE 2. - Distribution of litters by year, season and month of farrow.

Year	Spring						Fall					Year Total
	Jan.	Feb.	Mar.	Apr.	May	Total	July	Aug.	Sept.	Oct.	Total	
1934			2	11	1	14		1	5	2	8	22
1935			5	3		8		9	7		16	24
1936			12	7		19		4	11		15	34
1937		5	6	3	3	17		4	5	1	10	27
1938		2	10	2	1	15		10	3	2	15	30
1939		2	11	6		19		2	11		13	32
1940			15	3	1	19	1	1	9	2	13	32
1941			1	10	3	14		2	3	4	9	23
1942			15	6	1	22		5	10	2	17	39
1943		1	7	7	6	21	1	4	5		10	31
1944		4	14	9		27		3	12	3	18	45
1945		5	9	14		28	1	3	7	2	13	41
1946		2	11	11	3	27	1	5	7		13	40
1947		3	2	6	1	12	2	11	4	1	18	30
1949		7	16	3	1	27						27
1950							4	3	2	4	13	13
1951		8	7	4	5	24		15	2		17	41
1952	1	10	4	3		18	12	4			16	34
1953		11	12	1		24	18	5	4		27	51
Total	1	60	159	109	26	355	40	91	107	23	261	616

obviously the case for weaned litter size, because for a litter to be included the sow must have weaned pigs. While the magnitude of the results may differ from the values of the population, differences between particular classes are not likely to differ since the discarded data appeared to be distributed proportionally over all classes.

B. Classification

The data were classed by year, season, and six traits of the sow. Year and season were of natural grouping. The traits of the sow were divided into subclasses of discrete intervals as set forth with their respective class codes and ranges in table 3.

The particular traits studied were age of sow at farrowing, weight of sow at breeding, litter order, gestation length, weight change during gestation, and weight change during lactation. Age was calculated to the nearest month and gestation length to the nearest day. Weight change during gestation represents the difference between a weight taken at breeding and one taken immediately following parturition, while weight change during lactation represents the difference between the weight following parturition and one taken at the time that the litter was weaned.

An attempt was made to give equal range and frequency of observations to each sow subclass. This was limited by the tendency of breeding weight and weight changes during gestation and nursing to be distributed normally. Thus, to avoid classes at the upper and lower limits with low frequencies, broader classes were provided at these extremities. A similar modification was made at the upper limits of age and litter order since these two traits were skewed sharply to the left.

Table 3. - Subclass divisions of six major classifications of the sow.

Breeding weight		Farrowing age		Litter Order		Weight change				Gestation length	
						Gestation		Lactation			
Code	Range	Code	Range	Code	Range	Code	Range	Code	Range	Code	Range
b_1	177-250	a_1	10-15	li_1	1	g_1	-141- -1	la_1	-189- -91	le_1	109-111
b_2	251-290	a_2	16-21	li_2	2	g_2	0- 19	la_2	-90- -71	le_2	112
b_3	291-330	a_3	22-27	li_3	3	g_3	20- 39	la_3	-70- -51	le_3	113
b_4	331-370	a_4	28-33	li_4	4	g_4	40- 59	la_4	-50- -31	le_4	114
b_5	371-410	a_5	34-39	li_5	5	g_5	60- 79	la_5	-30- -11	le_5	115
b_6	411-450	a_6	40-45	li_6	6-11	g_6	80- 99	la_6	-10- 9	le_6	116
b_7	451-490	a_7	46-82			g_7	100-119	la_7	10-29	le_7	117
b_8	491-530					g_8	120-210	la_8	30-195	le_8	118
b_9	531-661									le_9	119-120

Performance traits of the litter were obtained in the subclasses of each major sow class. Litter traits considered were total number born, number born alive, number weaned, average litter weights of pigs living at birth, average pig weights of pigs living at birth, average pig weaning weights, and total litter weaning weights. All litters were weaned at 56 days of age.

C. Description

Year and Season. - Year and season means for six classes of the sow and nine performance traits of the litter are shown in table 4.

All traits of the sow show some yearly fluctuation, but show no evidence of annual trends. Breeding weight, farrowing age and litter order exhibit similar patterns of yearly fluctuations. Weight changes during gestation and lactation show wide variation between years but exhibit no distinct pattern either in relation to one another or to other traits. Their wide variation may reflect yearly differences in climatic and feed conditions. Gestation length showed extremely small yearly differences.

Since only two seasons, spring and fall, were involved it is not possible to establish any patterns of trends; however, the differences present are small and not likely to be important.

The lack of annual trends or large seasonal differences in the attributes of the sow would indicate that the general management and breeding regime under which the herd was maintained did not undergo any directional change during the period studied.

Year means for litter performance may be modified because of differences in sow traits. However, a distinct annual trend is apparent, characterized by lower weaning numbers, pig weaning weights and litter weaning weights during the second half of the period.

TABLE 4 - Year and Season means for six classifications of sows and nine performance traits of the litter.

Year of Season	Code	F	Means for sow traits: Breeding weight (lb.)	Farrowing age (mo.)	Litter order	Gestation length (day)	Wt. Changes: Gestation (lb.)	Wt. Changes: Lactation (lb.)	Means for litter performance: Litter size: Total born	Litter size: Born Alive	Litter size: Wean.	Percent loss: Stillbirth	Percent loss: Postnatal	Pig weights: Birth (lb.)	Pig weights: Wean. (lb.)	Litter weights: Birth (lb.)	Litter weights: Wean. (lb.)
1934	y1	22	443.3	30.6	3.0	115.3	48.5	-10.9	10.6	9.6	6.9	9.0	28.3	2.54	32.8	24.5	226.8
1935	y2	24	378.8	23.1	2.5	115.6	60.3	-19.3	11.2	10.5	7.9	6.3	24.6	2.56	31.6	27.0	250.2
1936	y3	34	405.8	28.6	3.6	115.4	41.9	-19.8	11.6	11.0	8.4	5.3	24.0	2.73	28.9	30.1	242.0
1937	y4	27	434.4	31.0	3.9	114.6	45.5	- 3.6	11.9	10.7	8.2	10.0	23.2	2.72	31.1	29.1	255.8
1938	y5	30	407.5	29.5	3.7	114.4	71.4	-20.9	12.4	11.4	9.4	8.0	17.5	3.02	32.3	34.6	304.3
1939	y6	32	444.2	31.4	4.1	115.4	75.5	-33.6	11.9	11.2	8.7	6.0	21.8	2.87	29.1	32.0	253.5
1940	y7	32	416.6	28.4	3.7	115.5	71.9	-30.8	11.3	10.6	8.6	6.9	18.9	2.97	30.3	31.4	259.1
1941	y8	23	443.3	34.8	4.5	115.0	96.1	-40.0	12.3	11.2	8.8	8.8	21.7	2.88	32.5	32.4	285.2
1942	y9	39	423.4	29.2	3.6	114.8	77.3	-36.0	10.4	9.5	7.8	8.7	17.1	3.04	32.1	28.8	252.2
1943	y10	31	409.9	30.2	3.6	114.6	78.4	-39.5	11.1	10.4	8.0	6.4	23.3	2.97	31.1	30.9	247.6
1944	y11	45	429.4	31.8	3.9	114.5	85.5	-56.0	10.9	10.4	7.4	7.1	28.7	2.87	27.7	29.8	204.7
1945	y12	41	433.4	35.1	4.2	114.8	84.7	-42.4	10.7	10.2	7.0	5.2	31.4	2.82	26.8	28.7	186.9
1946	y13	40	421.4	33.0	3.9	114.5	70.2	- 4.5	10.3	9.9	6.9	4.1	30.0	2.74	28.9	27.1	200.0
1947	y14	30	371.3	28.0	3.1	114.9	71.8	-16.1	11.5	11.1	7.3	3.5	34.7	2.74	25.2	30.6	183.2
1949	y16	27	357.2	27.5	3.1	114.6	60.2	-30.4	11.6	10.7	7.8	9.2	26.6	2.93	25.4	31.4	199.7
1950	y17	13	382.3	28.9	3.7	115.5	140.0	-61.9	10.8	9.5	7.8	12.1	17.7	2.66	29.1	25.4	228.2
1951	y18	41	374.2	24.6	2.9	115.4	82.0	-61.7	10.2	9.7	7.3	5.5	24.4	2.61	26.4	25.3	193.3
1952	y19	34	416.8	31.0	3.4	113.8	54.8	-43.4	11.1	10.1	7.7	8.8	23.6	2.56	31.1	25.9	240.6
1953	y20	51	405.3	28.6	2.9	114.0	64.7	-26.3	10.4	9.4	7.6	10.1	18.8	2.75	30.8	25.8	234.5
Spring	s1	355	414.3	30.1	3.5	114.9	73.9	-36.2	11.1	10.2	7.6	7.5	25.9	2.85	28.8	29.2	218.8
Fall	s2	261	405.9	29.5	3.5	114.7	65.8	-25.6	11.1	10.4	8.1	6.3	22.0	2.73	30.5	28.5	248.4

The average number of pigs weaned from fall litters exceeded those from spring litters by 0.5 pigs to provide the only apparent seasonal difference in litter performance.

Relationships Between Traits of the Sow and the Associated Trends in Litter Performance. - The means for all sow traits within each other (table 5) show that very distinct relationships exist. A visual appraisal of these relationships may be obtained from an examination of the frequency distribution of each trait within all others (table 6). The actual correlations that exist are given in table 7.

The correlations of breeding weight with age at farrowing and litter order are .79 and .76 respectively, while that between age at farrowing and litter order is .96. These correlations compare with values of .94, .95 and .96 between age and litter order reported by Kozeluka (14) for three different groups of sows; and of .60 for weight and age of gilt at first mating reported by Stewart (25).

A negative correlation of -.38 existed between increases in breeding weight and weight change during gestation. This is in general agreement with Zeller et al. (28) but contrary to Stewart (25) who found a correlation of .14 between age and weight gain during gestation. It should be noted that Stewart worked only with gilts, while the population considered here and by Zeller et al. included females of several age groups. Examination of the means and frequency distributions indicates that while this correlation existed throughout the population as a whole it was particularly dependent upon the tendency of young sows to gain considerably more than the population average. Slight

TABLE 5 - Sow trait and litter performance means within subclasses of six major classifications of the sow.

			Means for sow traits						Means for litter performance								
							Wt. changes		Litter size			Percent Loss		Pig weights		Litter weights	
Trait	Code	F	Breeding weight (lb.)	Farrowing age (mo.)	Litter order	Gestation length (days)	Gestation (lb.)	Lactation (lb.)	Total born	Born Alive	Total Weaned	Stillbirths	Postnatal	Birth (lb.)	Wean. (lb.)	Birth (lb.)	Wean. (lb.)
Breeding Weight (lb.)	b1	57	231.6	11.2	1.0	115.0	102.8	- 6.2	8.6	8.4	6.5	3.1	22.1	2.59	25.9	21.6	168.4
	b2	51	267.6	13.2	1.2	114.5	99.0	-31.6	9.7	9.4	7.9	2.8	16.3	2.55	28.4	24.0	223.1
	b3	39	314.1	18.5	1.9	114.8	97.5	-37.3	10.0	9.7	8.0	3.6	18.0	2.82	27.9	27.3	221.5
	b4	67	354.4	22.8	2.6	114.9	69.4	-34.1	11.2	10.5	8.4	5.6	19.8	2.92	30.3	30.8	256.1
	b5	79	392.3	26.8	3.2	114.8	74.2	-41.3	11.2	10.6	8.2	5.5	23.0	2.78	29.7	29.5	242.7
	b6	91	432.2	31.6	3.8	114.9	66.4	-28.8	11.5	10.7	7.6	7.1	29.2	2.78	30.3	29.8	229.7
	b7	87	471.4	37.7	4.8	114.5	63.6	-37.6	12.2	11.2	8.2	8.0	26.5	2.80	29.8	31.3	244.4
	b8	70	510.8	43.4	5.4	114.8	49.8	-33.5	12.1	10.9	8.3	9.8	23.7	2.88	29.8	31.4	247.6
	b9	75	574.3	46.4	5.7	114.7	36.3	-31.2	11.6	10.3	7.2	11.6	30.3	2.94	31.7	30.4	227.7
Farrowing Age (mo.)	a1	120	259.0	12.4	1.0	114.7	-99.8	-19.2	9.1	8.8	7.1	3.5	19.9	2.56	26.7	22.6	188.4
	a2	79	358.9	18.0	1.9	115.0	75.2	-34.8	10.9	10.4	8.2	4.1	20.8	2.74	29.1	28.6	239.9
	a3	95	414.9	24.0	2.7	114.9	66.5	-32.4	11.2	10.4	8.1	6.8	22.4	2.82	31.1	29.4	251.8
	a4	94	438.6	29.7	3.6	114.5	61.7	-31.1	11.8	11.0	7.8	7.0	29.2	2.84	30.0	31.2	232.9
	a5	76	467.5	35.7	4.4	114.8	66.2	-39.9	12.2	11.4	8.7	6.7	23.9	2.81	30.0	32.0	259.7
	a6	52	497.4	42.3	5.8	114.6	43.7	-26.9	11.6	10.8	7.6	7.4	29.1	2.82	30.3	30.4	231.5
	a7	100	515.4	55.2	6.8	114.8	60.5	-40.5	11.8	10.3	7.6	12.6	25.9	3.02	30.6	31.2	233.7
Litter Order	li1	130	267.5	12.5	1.0	114.8	96.3	-20.6	9.3	9.0	7.0	3.7	21.4	2.58	26.7	23.1	188.4
	li2	100	377.7	20.3	2.0	115.0	72.3	-33.5	11.0	10.4	8.2	4.8	21.4	2.73	29.8	28.5	244.8
	li3	105	425.9	26.6	3.0	114.6	64.8	-32.1	11.3	10.5	8.1	7.3	23.0	2.85	30.7	29.6	247.6
	li4	99	452.2	32.8	4.0	114.6	62.6	-35.0	11.8	11.0	8.0	6.8	27.3	2.83	30.4	31.3	243.2
	li5	65	473.9	38.8	5.0	114.9	55.0	-24.9	11.9	11.0	8.1	8.0	26.1	2.81	29.4	30.9	238.3
	li6	117	514.2	52.7	7.2	114.8	60.3	-43.3	12.0	10.7	7.8	11.0	26.8	3.00	30.5	32.0	239.2
Gestation Length (days)	le1	9	452.6	35.9	3.8	110.8	50.0	-40.4	11.9	10.6	6.0	11.2	43.2	2.79	30.1	29.4	180.9
	le2	23	421.4	34.8	3.8	112.0	80.5	-43.6	11.1	10.3	7.1	7.3	30.8	2.76	32.5	30.5	231.9
	le3	74	411.9	30.5	3.5	113.0	56.5	-27.8	11.5	10.8	7.6	6.1	29.4	2.65	29.6	28.5	225.5
	le4	147	413.3	30.0	3.6	114.0	67.5	-43.7	11.4	10.6	8.0	7.1	24.3	2.80	29.9	29.7	240.4
	le5	175	405.4	28.5	3.4	115.0	72.1	-34.5	11.2	10.5	8.3	6.0	21.3	2.80	28.9	29.4	239.9
	le6	118	403.4	29.6	3.5	116.0	74.0	-22.8	10.7	9.8	7.5	7.8	23.5	2.86	29.6	28.1	222.2
	le7	50	410.8	29.4	3.5	117.0	84.5	-39.4	10.6	9.7	7.8	8.5	19.6	2.86	28.5	27.6	221.7
	le8	15	449.3	33.9	4.1	118.0	72.2	-36.9	9.9	9.1	5.9	8.1	35.0	2.80	31.2	25.5	185.3
	le9	5	438.0	30.4	3.4	119.2	6.6	-18.8	10.8	9.8	7.4	9.3	24.5	2.84	39.6	27.8	293.2
Gestation Weight Change (lb.)	g1	50	487.6	36.0	4.4	114.4	-34.4	9.4	11.4	10.4	7.9	9.4	23.4	2.68	29.5	27.8	234.5
	g2	46	470.6	31.4	4.1	114.8	11.9	- 3.8	11.2	10.5	7.6	7.0	27.0	2.79	28.7	29.2	218.8
	g3	64	465.8	34.4	4.2	114.8	31.5	-16.6	11.5	10.4	7.9	9.4	24.5	2.80	31.3	29.1	245.9
	g4	80	425.7	31.0	3.7	114.8	48.4	-17.0	11.5	10.6	7.9	7.9	25.2	2.81	30.1	29.7	237.8
	g5	90	397.6	28.8	3.3	114.7	67.6	-32.6	10.6	9.9	7.7	6.7	22.3	2.85	29.9	28.1	229.2
	g6	99	397.2	28.6	3.4	114.9	88.5	-42.7	11.6	10.7	7.7	7.2	28.2	2.82	29.0	30.3	223.2
	g7	86	370.8	26.6	3.1	114.6	108.2	-46.6	11.0	10.5	8.1	4.6	23.1	2.82	29.4	29.6	237.0
	g8	101	357.8	26.0	3.0	115.1	143.8	-61.8	10.5	9.9	7.8	7.5	21.0	2.78	29.0	27.5	226.4
Lactation Weight Change (lb.)	la1	74	443.9	36.3	4.4	114.9	96.9	-116.6	11.9	11.1	8.8	7.1	20.8	2.89	30.0	32.0	262.9
	la2	60	410.0	29.6	3.7	114.6	99.4	-79.3	11.2	10.6	8.8	5.8	16.2	2.96	28.9	31.2	255.9
	la3	87	415.2	31.5	3.7	114.5	87.3	-60.8	11.3	10.6	8.3	6.9	21.4	2.84	30.1	30.0	250.2
	la4	82	393.6	28.2	3.2	114.5	84.2	-40.9	11.3	10.8	8.2	4.3	24.4	2.77	29.4	29.9	239.8
	la5	93	393.0	27.9	3.2	115.0	66.9	-20.9	11.0	10.3	7.6	6.3	25.7	2.74	29.0	28.2	221.5
	la6	100	406.6	27.7	3.3	114.7	54.3	- 2.4	10.7	9.9	7.5	7.6	24.6	2.76	29.5	27.4	220.6
	la7	56	426.6	29.6	3.5	115.0	35.0	21.2	11.0	10.2	7.3	6.5	28.9	2.71	29.9	27.8	217.7
	la8	64	407.2	28.8	3.5	114.8	33.7	54.3	10.4	9.1	6.0	12.5	34.4	2.75	29.9	25.0	178.7
Mean			410.6	29.8	3.5	114.8	70.4	-30.9	11.1	10.3	7.8	7.0	24.3	2.80	29.6	28.9	231.4

TABLE 6 - Frequency distributions of the litters within subclasses of six major classifications of the sow.

Class	Code	Mean	F	Farrowing age (mo.)							Litter order					
	Code			a1	a2	a3	a4	a5	a6	a7	li1	li2	li3	li4	li5	li6
		Mean		12	18	24	30	36	42	55	1	2	3	4	5	7
			F	120	79	95	94	76	52	100	130	100	105	99	65	117
Breeding weight (lb.)	b1	232	57	56	1						56	1				
	b2	268	51	43	6	1	1				44	5	1	1		
	b3	314	39	18	11	5	2	3			18	12	5	2	2	
	b4	354	67	2	33	15	12	2	2	1	5	36	15	8	2	1
	b5	392	79	1	22	23	17	6	5	5	7	23	23	14	5	7
	b6	432	91		4	30	29	13	7	8		15	26	29	13	8
	b7	471	87		2	13	15	27	11	19		4	20	17	21	25
	b8	511	70			7	8	15	8	32		2	10	13	11	34
	b9	574	75			1	10	10	19	35		2	5	15	11	42
Farrowing age (mo.)	a1	12	120								120					
	a2	18	79								9	70				
	a3	24	95									24	71			
	a4	30	94								1	5	24	64		
	a5	36	76									1	8	26	41	
	a6	42	52										1	6	19	26
	a7	55	100										1	3	5	91
Litter order	li1	1	130													
	li2	2	100													
	li3	3	105													
	li4	4	99													
	li5	5	65													
	li6	7	117													
Gestation weight change (lb.)	g1	-34	50													
	g2	12	46													
	g3	32	64													
	g4	48	80													
	g5	68	90													
	g6	88	99													
	g7	108	86													
	g8	144	101													
Lactation weight change (lb.)	la1	-117	74													
	la2	-79	60													
	la4	-61	87													
	la5	-41	82													
	la6	-21	93													
	la7	-2	100													
	la8	21	56													
	la9	54	64													

Code	Gestation weight change (lb.)								Lactation weight change (lb.)							
Code	g1	g2	g3	g4	g5	g6	g7	g8	la1	la2	la3	la4	la5	la6	la7	la8
Mean	-34	12	32	48	68	88	108	144	-117	-79	-61	-41	-21	-2	21	54
F	50	46	64	80	90	99	86	101	74	60	87	82	93	100	56	64
b1			1	6	6	15	10	19		4	4	8	12	15	6	8
b2	2		2	2	6	8	18	13	4	2	9	11	11	6	3	5
b3		2		6	11	4	3	13	6	6	5	6	3	4	6	3
b4	4	2	3	12	15	10	11	10	7	8	14	7	9	10	4	8
b5	1	7	8	8	19	16	10	10	10	8	15	13	16	11	1	5
b6	9	8	14	13	7	12	13	15	8	12	8	14	15	11	12	11
b7	7	11	13	11	8	12	12	13	12	11	13	7	13	18	4	9
b8	11	5	12	11	8	14	4	5	16	5	6	9	5	14	8	7
b9	16	11	11	11	10	8	5	3	11	4	13	7	9	11	12	8
a1	2	1	3	11	17	24	27	35	8	8	13	18	23	22	12	16
a2	1	5	6	12	15	15	14	11	4	13	14	14	9	14	5	6
a3	9	8	13	11	16	13	11	14	10	9	13	11	19	18	6	9
a4	12	8	10	15	15	13	6	15	15	4	13	13	13	13	13	10
a5	5	11	12	9	7	10	11	11	8	13	13	9	10	12	7	4
a6	9	5	8	9	6	5	7	3	9	4	5	5	5	9	6	9
a7	12	8	12	13	14	19	10	12	20	9	16	12	14	12	7	10
li1	2	3	4	12	19	28	27	35	9	8	15	20	26	24	12	16
li2	5	7	9	14	18	16	18	13	7	14	15	15	15	16	8	10
li3	12	8	12	15	18	14	9	17	13	10	14	14	19	18	9	8
li4	11	11	10	14	15	13	11	14	13	9	16	15	11	16	10	9
li5	6	7	15	11	5	7	7	7	6	7	9	6	6	14	8	9
li6	14	10	14	14	15	21	14	15	26	12	18	12	16	12	9	12
g1									4		1	2	6	7	14	16
g2										2	4	5	8	11	5	11
g3									4	3	7	4	12	18	8	8
g4									7	3	7	11	12	22	10	8
g5									8	7	18	10	17	17	6	7
g6									14	15	13	17	18	11	7	4
g7									12	14	15	19	10	6	3	7
g8									25	16	22	14	10	8	3	3

Code	Gestation length (day)								
Code	le1	le2	le3	le4	le5	le6	le7	le8	le9
Mean	111	112	113	114	115	116	117	118	119
F	9	23	74	147	175	118	50	15	5
b1	1	2	7	11	13	14	8	1	
b2		2	9	11	15	11	3		
b3		2	3	8	16	9	1		
b4	1	1	4	20	21	13	5	1	1
b5		6	12	17	22	9	8	3	2
b6	2	1	8	24	27	19	7	3	
b7	1	1	11	24	27	15	5	3	
b8	3	3	10	12	16	18	6	1	1
b9	1	5	10	20	18	10	7	3	1
a1	1	5	15	24	36	27	11	1	
a2	1		9	17	27	13	8	2	2
a3		2	10	23	33	18	5	3	1
a4	2	3	15	32	16	16	7	2	1
a5	2	4	4	19	25	14	6	2	
a6	1	4	7	12	13	9	4	2	
a7	2	5	14	20	25	21	9	3	1
li1	2	5	17	24	37	28	15	2	
li2		2	13	23	33	16	8	2	3
li3	2	2	10	30	33	20	6	2	
li4	2	4	15	30	21	19	4	3	1
li5	1	3	2	18	20	14	5	2	
li6	2	7	17	22	31	21	12	4	1
g1	3	1	12	11	10	9	2	2	
g2		1	7	8	19	6	4	1	
g3	1	2	7	20	17	8	5	3	1
g4	1	2	10	23	18	20	4		2
g5		5	8	25	21	24	6	1	
g6	2	3	9	22	36	15	9	1	2
g7	1	5	13	19	23	15	7	3	
g8	1	4	8	19	31	21	13	4	
la1	2	4	9	13	21	10	10	4	1
la2	1	4	3	18	22	8	2	2	
la4		4	14	26	18	16	9		
la5	2	4	9	18	27	14	6	2	
la6	1	2	5	22	29	22	8	2	2
la7	1	2	19	21	30	18	8	1	
la8	2		5	14	15	14	3	1	2
la9		3	10	15	13	16	4	3	

Table 7 - Correlations between six major classifications of the sow

Sow Class	Farrowing age	Litter order	Gestation weight change	Lactation weight change	Gestation length
Breeding weight	.79	.76	-.38	-.06	-.02
Farrowing age		.96	-.24	-.11	-.03
Litter order			-.08	-.01	-.02
Gestation weight change				-.42	-.01
Lactation weight change					.05

evidence of a similar relationship existed in classes of age of sow and litter order which provided correlations of -.24 and -.08 respectively with gestation weight change. On the other hand gestation weight change was correlated with lactation weight change ($r = -0.42$) which in turn tended to be uniformly distributed over all classes of breeding weight, age at farrowing and litter order with small negative correlations in each case.

It is of interest to note that the fifty sows which lost weight during gestation, were as a group the heaviest at breeding and were the only group registering positive gain in weight during lactation.

Gestation length was not noticeably associated with any sow traits.

Traits of the sow and relationships between them become of importance when litter performance is associated with them. The means of litter performance within each sow subclass (table 5) indicates where relationships may exist.

Breeding weight, age at farrow and litter order were all associated with distinct and similar trends in litter performance. Because of the high correlation between these traits, it would appear that within limits they combine with a common function, time, in expressing a similar characteristic of the sow. The trends present show the nature of the variation which is characterized by increases in litter size at birth with increasing class values to a peak in performance which is usually followed by a decline, and by a trend in weaning numbers which tends to be flat over the central classes and drop at both extremities. Mortality in terms of percentage stillbirths and postnatal losses shows a progressive increase throughout all classes.

Birth and weaning pig and litter weights increase sharply during the first two or three classes and level out over those remaining.

The percent of stillbirths decreased irregularly with increases in weight during gestation. This may reflect a true effect of this class or may simply reflect its negative correlation with classes of breeding weight, age at farrowing and litter order which showed increases in the percentage of stillbirths as their class values increased. Other than this, no trends in litter performance were apparent as weight change during gestation varied. This generally agrees with Donald and Fleming (6) who were unable to enhance litter performance by liberal feeding of sows during gestation, but is contrary to Zeller *et al*. (28) who reported a positive relationship between weight changes during gestation and subsequent litter size.

Increases in litter size and total weights at weaning were closely associated with increases in weight losses during lactation.

The association of litter performance with breeding weight, lactation weight change and gestation weight change raises a question as to how these three traits of the sow are interrelated. Increases in weight change during gestation were negatively correlated with increases in breeding weight and decreases in weight loss during lactation. Improved litter performance, up to a point, was positively associated with increases in breeding weight and with decreases in lactation weight change, but bore no relationship to gestation weight change.

A possible explanation concerning the relationship between breeding weight and gestation weight change might be that sows with large weight

gains during gestation are of two groups one which gained rapidly because they were younger and growing, but that performed poorly because of their age; and a second group that were thin having just produced a better than average litter, and that gained rapidly during gestation because of their condition and performed well because of their age and a tendency to repeat previous performance.

The relationship between gestation and lactation weight change could arise from the effect caused by loss of weight during the previous gestation. Sows losing heavily during gestation, if healthy, would have likely been retained in the herd, since they would have likely produced superior litters. Such sows would gain rapidly during the subsequent gestation because of their condition and since they might be expected to repeat previous performance would produce well and lose heavily in body weight during the subsequent lactation causing the relationship observed.

Consequently weight changes of the sow during gestation may be regarded as not likely related to litter performance, but a trait associated with age and condition at time of breeding.

A slight association indicated that sows with shorter gestation lengths farrowed larger litters. Weaning numbers were highest from classes of intermediate length, while average pig weights were lightest in these classes, presumably reflecting the effect of larger litter sizes. Mortality, in terms of percentage stillbirths and postnatal losses, tended to be highest in those gestation length classes with the highest average age, litter order and breeding weight.

4. METHOD OF ANALYSIS

A. Estimation of Environmental Parameters

The method of least squares was used to obtain an unbiased appraisal of the importance of breeding weight, weight changes during nursing, year and season. The theory of this method of analysis has been discussed by Kempthorne (12) and others. The specific procedure used was outlined by Fredeen (8).

The method of least squares provides for unbiased estimates of the mean effect of subclasses with disproportionate frequencies. The procedure is to set up a linear model of the individual observations in terms of

(1) An overall population mean (μ)

(2) An effect due to specific sources of variation (parameters)

(3) An overall chance or random error effect.

This establishes a series of equations equal to the number of parameters being estimated which are solved simultaneously in such a way that the sums of squares of deviations of individual observations from the model are a minimum.

To provide valid estimates of the parameters they must combine additively in their effect on the dependent variables. This implies that the independent variables must not be correlated.

Age of sow, litter order and breeding weight were highly correlated and appeared to be mutually dependent in their effect on litter performance. Selection of one of these three as a source of environmental variation was to a certain extent arbitrary since sufficient data were not available to examine these traits within each other except at a preliminary level. Such

preliminary examination indicated that of the three, breeding weight was likely the most important as a source of variation. It was also believed that breeding weight was a more basic biological concept of an animal -- in that age is entirely a function of time, and litter order is closely dependent upon time -- while breeding weight is a function of time, health, vigor, the dietary regime as well as an expression of the physiological stage of development.

Weight change during gestation was discarded because it was closely associated with breeding weight and weight change during lactation, as well as being a factor that did not exert any consistent effect on litter performance. Finally, gestation length was excluded because other workers (3, 23) have not found it to influence litter performance appreciably and because the variation within it was quite low (coefficient of variation of 0.02 percent).

The dependent variables considered were restricted to litter sizes and litter weights. Average pig weights were excluded because an estimation of the effect on total litter weight will include any average effect.

The foregoing considerations led to the following linear model as representative of the effects of environmental factors selected for study.

$$Y_{ijklm} = \mu + y_i + s_j + b_k + la_l + e_{ijkl}$$

where Y_{ijklm} is a record of the m^{th} litter born in the i^{th} year during the j^{th} season to a dam of the k^{th} breeding weight class and l^{th} weight change during lactation class.

μ is the mean effect. It is the portion of each individual observation common to all litters. In a balanced experiment it would represent the overall mean.

y_i is the effect common to all litters farrowed in the i^{th} year. $i = 1$ to 19. It represents the environmental influence of years.

s_j is the effect common to all litters farrowed in the j^{th} season. $j = 1$ to 2. It represents the environmental influence of spring and fall seasons.

b_k is the effect common to all litters farrowed by dams in the k^{th} breeding weight class. $k = 1$ to 8. It represents the environmental influences between various breeding weights of the dam. It will also include some influences of age and litter order since they are highly correlated with breeding weight and presumably mutually dependent in their effects on litter performance.

la_l is the effect common to litters farrowed by dams in the l^{th} weight change in nursing class. $l = 1$ to 8. It is the environmental influence of the change in weight of the sow during lactation.

e_{ijkl} is the effect peculiar to each observation and includes variation due to chance, errors, or other factors which are not recognized in the model.

The complete model provided 39 independent variables consisting of 19 years, two seasons, eight breeding weight subclasses, and eight weight change in lactation subclasses, plus an overall equation representing the mean.

The frequencies of each independent variable were established in a matrix form designated the "A" matrix which was equated to the total of the dependent variables referred to as the Right Hand Sides (R.H.S.). This provided a series of 39 normal equations for simultaneous solution composed of a 39 x 39 A matrix and a block of five by 39 Right Hand Sides (each column of the block represents a single aspect of litter performance). To this was added an identity matrix designated "I" which provided for computing the standard errors of the estimates of the environmental effects.

This provided a system of the form

$$A.I = R.H.S.$$

Unique solution, however, was not possible since, within the system, each major class was correlated. This may be seen by the fact that the sum of the frequencies of each major class in the A matrix and of each major class total in the R.H.S.'s are equal to the frequencies and totals respectively of all other major classes and also to those of the μ equation.

To obtain independence and provide for unique solution the simplest procedure was to delete from the matrix the complete equation for the largest component of each major class. This led to the deletion of Y_{20}, s_1, b_6, and la_6 and left a 35 by 41 system for solution. The estimates of the individual effects were obtained as the difference from the deleted subclass. For example estimates of the effect of breeding weights were resolved in the form

$$(b_1 - b_6),\ (b_2 - b_6),\ (b_3 - b_6),\ \text{etc.}$$

The frequencies necessary to establish the "A" matrix and the totals required for the R.H.S. were computed by use of I.B.M. equipment. Solution of the matrix was done by McClelland Laboratory, Toronto, with an electronic computer known as the Ferut.

5. RESULTS AND DISCUSSION

A. Estimates of Environmental Parameters

The least square constants, originally obtained as the difference from the deleted subclass, were recalculated and are presented as the difference from subclass one in the case of years; and as the difference between all subclasses in the case of breeding weight and lactation weight change. The advantage of such a classification is that trends throughout years as a whole, and important differences as well as trends in breeding weight and weight change during lactation will be more clearly illustrated.

Years. - Large year differences (table 8) in litter performance do exist and are of sufficient magnitude to invalidate comparisons between years. A general trend existed throughout years as a whole characterized by a lower level of performance for weaning numbers and weights during the latter half of the period considered. Figure 1 shows yearly performance of weaned litter size and total litter weaning weight obtained from the least square constants, and of average pig weights at weaning obtained from the uncorrected data. The tendency for weaned litter size and average pig weights at weaning to fall simultaneously is contrary to the trends observed by others (5, 16, 26) from studies on the relationships among litter mates. It would therefore appear that both growth and livability suffered a general decline.

The higher average pig weights observed in the last two years undoubtedly reflect the effect of antibiotic feed supplements which came into use at that time in the University of Alberta's swine creep rations.

TABLE 8 - Estimates of the environmental effects of year and season on five performance traits of the litter.

Year	Total pigs born	Pigs born Alive	Pigs Weaned	Litter birth Weight (lb.)	Litter Weaning Weight (lb.)
y2-y1	1.07	0.95	0.64	3.27	10.26
y3-y1	1.26	1.39	1.20	5.77	7.29
y4-y1	1.32	1.02	1.22	4.79	28.10
y5-y1	2.12	1.77	2.18	10.67	68.15
y6-y1	1.31	1.41	1.34	6.87	12.01
y7-y1	0.75	0.65	1.10	6.42	15.47
y8-y1	1.45	1.17	1.38	6.84	42.24
y9-y1	0.12	0.07	0.58	4.83	15.33
y10-y1	0.38	0.63	0.51	5.85	5.68
y11-y1	0.06	0.12	-0.46	3.38	-45.89
y12-y1	0.05	0.18	0.34	3.37	-47.85
y13-y1	0.21	0.64	0.23	3.94	-10.67
y14-y1	1.76	1.98	0.26	8.05	-38.19
y15-y1	1.66	1.33	0.78	7.53	-20.02
y17-y1	0.31	-0.75	-0.41	0.22	-37.19
y18-y1	0.00	0.00	-0.47	0.49	-51.63
y19-y1	0.43	0.24	0.21	0.64	-0.17
y20-y1	0.15	-0.21	0.30	1.77	-3.21
y1 mean	10.6	9.6	6.9	24.5	226.8
s2-s1	0.22	0.41	0.78	0.28	35.62
s1 mean	11.1	10.2	7.6	29.2	218.8

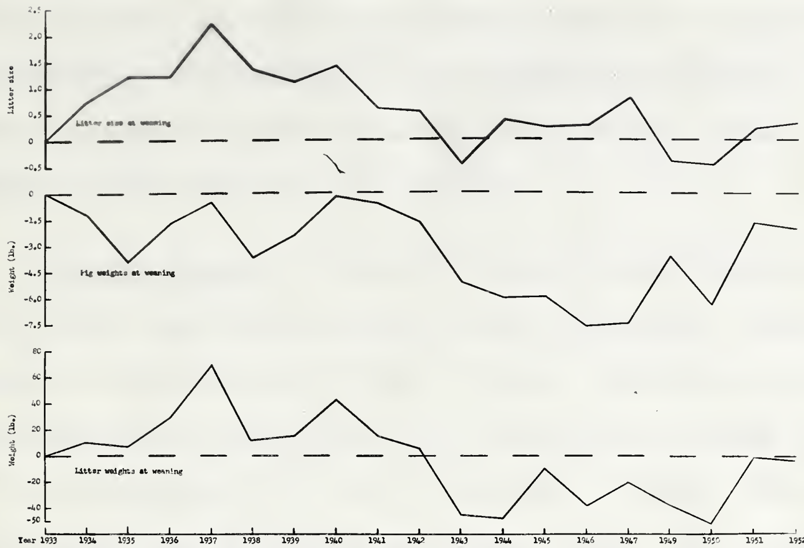

FIGURE 1. - Trends in litter performance associated with years shown as the difference from the first year.

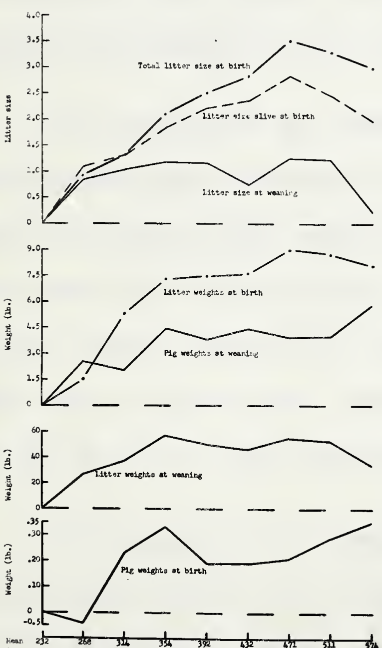

FIGURE 2. - Trends in litter performance associated with changes in breeding weight, shown as the difference from class 1.

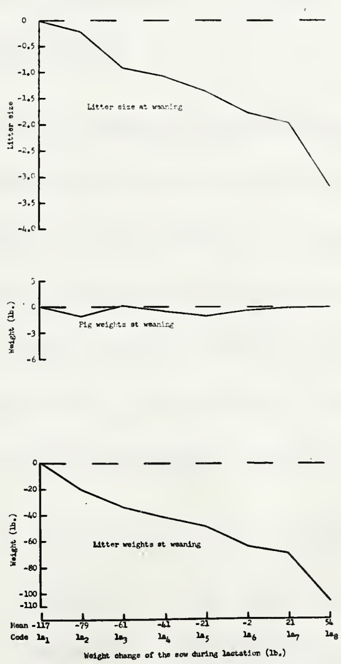

FIGURE 3. - Trends in litter performance associated with changes in weight of the sow during lactation shown as the difference from class 1.

Season. - The average number of pigs weaned and the total litter weights of fall litters exceeded those of spring litters by .78 pigs and 35.62 pounds respectively. The increase in total litter weights reflect very little more than the effect of numbers since the average weights of fall pigs exceeded those of spring pigs by only 1.7 pounds.

Breeding Weight. - A biological reason exists to suspect that variations in breeding weight might influence litter performance. Hence, the environmental effects of breeding weight (table 9) can be regarded as correction factors for the adjustment of observations where differences are likely to be large enough to bias comparisons. In table 9 an asterisk is placed after each constant that is at least twice as large as its standard error. The portion of each section in which asterisks appear are therefore represented by those classes between which differences are likely to be important.

The magnitude of the constants would indicate that breeding weight contributed materially to variation in total litter size at birth in classes up to and including b_4 (mean breeding weight of 354 pounds), in numbers born alive in classes up to and including class b_3 (mean breeding weight of 314 pounds), and in numbers weaned in classes b_1 and b_9 (mean breeding weight of 232 and 574 pounds respectively). Performance of the remaining classes, in each case tended to be at a level that did not differ markedly from one another.

Differences in litter weights at birth and weaning reflect variation in both average numbers and average pig weights. In general, however, the important differences appear between the same classes in which differences in litter numbers are large indicating total litter weight to be primarily a function of litter numbers.

In cases where whole number corrections are desired for adjusting data on litter size for individual comparisons the most applicable correction would be obtained by rounding the constants of table 9. Such rounding would give values of zero to four for litter size at birth, zero to three for litter size alive at birth, and zero to one for litter size at weaning. In the case of weaned litter size the necessary correction of one would be restricted to the first and last classes.

Trends in litter performance associated with breeding weight are illustrated graphically in figure 2. Litter sizes and total litter weights represent the least square constants, while average pig weights at birth and weaning represent the uncorrected data.

Total litter numbers at birth increased progressively to a maximum in class b_7 (mean breeding weight of 471 pounds) after which a slight decline occurred; numbers alive at birth followed a similar pattern except that differences between the two increased continuously, indicating the proportion of stillbirths increased as weight of sow at breeding increased. Weaning numbers increased by about one pig from the first to the second class and thereafter tended to remain constant to class b_8 with the exception of a slight drop at class b_6. Between classes b_8 and b_9 a sharp decline occurred. No logical explanation exists for the drop in weaning numbers noted at class b_6 other than random variation. Its chief importance lies in the fact that it possibly exerted an influence on average pig weights and total litter weights at weaning.

The difference in the general trends between birth and weaning numbers reflects the effect of two opposing forces which affect litter size as breeding

TABLE 9 - Estimates of the environmental effect of breeding weight on five litter performance traits.[1]

Litter Trait	Mean Code	Breeding weight 232 b_1	268 b_2	314 b_3	354 b_4	392 b_5	432 b_6	471 b_7	511 b_8	574 b_9
Total pigs born	b1	8.61	.94*	1.30*	2.10*	2.51*	2.83*	3.51*	3.29*	2.97*
	b2		9.67	.36	1.16*	1.57*	1.89*	2.57*	2.35*	2.03*
	b3			10.05	.80*	1.21*	1.53*	2.21*	1.99*	1.68*
	b4				11.16	.41	.73	1.41*	1.19*	.88*
	b5					11.24	.32	1.00*	.78*	.47
	b6						11.53	.68	.46	.14
	b7							12.27	-.22	-.54
	b8								12.09	-.31
	b9									11.65
Pigs born alive	b1	8.35	1.09*	1.32*	1.84*	2.21*	2.35*	2.81*	2.44*	1.95*
	b2		9.39	.22	.75*	1.12*	1.26*	1.72*	1.35*	.86*
	b3			9.96	.52*	.90*	1.04*	1.49*	1.13*	.63
	b4				10.54	.37	.51	.97*	.60	.11
	b5					10.62	.14	.60	.23	-.26
	b6						10.71	.46	.09	-.40
	b7							11.17	-.37	-.86*
	b8								10.90	-.49
	b9									10.31
Pigs weaned	b1	6.51	.85*	1.09*	1.18*	1.16*	.75*	1.26*	1.24*	.23
	b2		7.86	.17	.32	-.30	-.10	.41	.39	-.62
	b3			7.95	.15	.13	-.27	.24	.22	-.79*
	b4				8.45	-.02	-.42	.09	.07	-.94*
	b5					8.18	-.40	.11	.09	-.92*
	b6						7.58	.51	.49	-.52
	b7							8.21	-.02	-1.03*
	b8								8.31	-1.01*
	b9									7.19
Litter birth weight (lb.)	b1	21.61	1.50	5.38*	7.16*	7.35*	7.47*	9.00*	8.72*	7.97*
	b2		23.96	3.88*	5.66*	5.85*	5.97*	7.50*	7.22*	6.47*
	b3			27.31	1.78	1.97*	2.09	3.62*	3.34*	2.59*
	b4				30.75	.19	.31	1.84*	1.56	.81
	b5					29.53	.12	1.65	1.37	.62
	b6						29.76	1.53	1.25	.50
	b7							31.30	-.28	-1.03
	b8								31.41	-.75
	b9									30.35
Litter weaning weight (lb.)	b1	168.40	26.50*	36.95*	57.16*	50.24*	46.20*	55.46*	52.42*	33.56*
	b2		223.14	10.45	30.66*	19.70	23.74	28.95*	25.95*	7.06
	b3			221.54	20.21	13.29	9.25	18.50	15.47	-3.39
	b4				256.13	-6.92	-10.96	-1.70	-4.74	-23.60*
	b5					242.68	-4.04	5.21	2.18	-16.67
	b6						229.67	9.26	6.23	-12.63
	b7							244.45	-3.03	-21.89*
	b8								247.57	-18.86
	b9									227.67

1 The leading diagonal gives the uncorrected mean of each subclass. Environmental effects are shown as the difference between row and column subclasses. e.g. ($b_2 - b_1 = .94$) ($b_3 - b_1 = 1.30$).

* An asterisk is placed after each constant that is equal to or greater than twice its standard error.

weight of the sow increases. On one hand increases in breeding weight, up to a point, tend to enhance litter performance in that birth numbers are larger; while on the other hand mortality in terms of stillbirths and losses during lactation increase with increases in breeding weight. The two effectively nullify each other so that weaned litter size remains constant during the major part of the life of a sow. The tendency for birth numbers to decline slightly in the later classes would indicate that senility as well as weight may become a factor in production at this time.

Average birth weights fell slightly from class b_1 to b_2 followed by a sharp increase to classes b_3 and b_4, after which a slight decline occured to class b_6 followed by a rise to class b_9. A possible explanation of this trend may be as follows: classes b_1 and b_2 are composed largely of gilts and since class b_2 farrowed larger litters a slight decline in average birth weights occurred. Similarly the decline in classes b_5, b_6 and b_7 over that of classes b_3 and b_4 may reflect increases in birth litter size; while the increases in average birth weights of the last two classes reflect decreases in birth numbers. Two levels of performance, then may exist, characteristic of either gilts or sows. Within each the differences in average pig birth weights may be largely accounted for by differences in birth numbers.

Average pig weights at weaning increased to class b_4, decreased slightly to a similar level in classes b_5, b_7 and b_8 and rose to maximum levels in classes b_6 and b_9 which were the classes in which a drop in weaning numbers occurred. From this it may be concluded that increases in breeding weight enhanced average pig weights up to class b_4, followed by a slight decline to

class b_5 after which class the average weaning weights were largely accounted for by variations in weaned litter size.

The curve for total litter weaning weight, of necessity, reflects the combined effect of average litter numbers and average pig weights. It rises progressively to a maximum at class b_4 at which time a flattening occurs with a slight depression at class b_6 and a somewhat sharper depression at class b_9. The lower average weaning numbers of these two classes were only partially offset by increases in average pig weights.

The observed trends in litter performance associated with breeding weight can be compared with the results of other workers, in a general way only, through the medium of the correlation between breeding weight, litter order and age of dam at farrowing since all other investigations are reported on the basis of the latter two. In this regard the pattern of results obtained here for breeding weight are basically similar to those reported by others (3, 7, 13, 15, 16; 18, 19, 20, 22) for age of sow or litter order with only minor variations which may well be accounted for by breed and environmental differences.

<u>Lactation Weight Change</u>. - Estimates of the environmental effects of weight losses during lactation on litter weights and numbers at weaning (table 10) show that increased weight loss during lactation was accompanied by a marked increase in the magnitude of both these litter traits. In that loss of body weight can be regarded as a function of milk production, these associations undoubtedly reflect the relationship between increased milk production, and enhanced survival presumably as a result of stronger and healthier pigs.

TABLE 10 - Estimates of the environmental relationship between weight changes of the sow during lactation and two performance traits of the litter.

Litter trait	Mean Code	-117 la_1	-79 la_2	-61 la_3	-41 la_4	-21 la_5	-2 la_6	21 la_7	54 la_8
		Lactation weight change							
Pigs Weaned	la1	8.77	-.21	-.91*	-1.09*	-1.37*	-1.79*	-1.97*	-3.22*
	la2		8.85	-.69*	-.87*	-1.16*	-1.58*	-1.76*	-3.01*
	la3			8.30	-.18	-.46	-.88*	-1.07*	-2.31*
	la4				8.15	-.29	-.70*	-.89*	-2.13*
	la5					7.65	-.42	-.60*	-1.85*
	la6						7.48	-.18	-1.43*
	la7							7.29	-1.25*
	la8								5.97
Litter Weaning Weight (lb.)	la1	262.92	-20.96	-34.41*	-41.93*	-50.44*	-64.09*	-70.69*	-107.00*
	la2		255.92	-13.45	-20.97*	-29.47*	-43.12*	-49.72*	-86.03*
	la3			250.16	-7.52	-16.02	-29.68*	-36.27*	-72.59*
	la4				239.77	-8.50	-22.16*	-28.76*	-65.07*
	la5					221.52	-13.65	-20.25*	-56.56*
	la6						220.60	-6.60	-42.91*
	la7							217.71	-36.31*
	la8								178.67

Figure 3 shows the trends in weaning number and litter weaning weight obtained from the least square constants, while that of average pig weight at weaning is represented by the uncorrected data in which case no appreciable differences are apparent. The lack of a definite trend in average pig weights would not have been expected in view of the findings of Zeller et al. (28) who reported a distinct relationship between heavy average weaning weights and large weight losses of the sow during lactation.

B. A preliminary examination of the relative importance of age at farrow and weight at breeding on litter numbers from gilts.

One hundred litters, all farrowed by gilts 11, 12 or 13 months of age, were sub-divided within age into two breeding weight classes of equal number consisting of the heaviest and lightest individuals respectively.

The entire hundred litters were then reclassified into three major breeding weight groups consisting of the lightest, middle, and heaviest one-third respectively. Each major breeding weight group was then sub divided into classes on the basis of age at farrowing. Litter sizes were calculated for each major and subclass for the two systems of classification (table 11).

Litter size in terms of total number born, number born alive and number weaned increased progressively throughout the major classes of breeding weight and throughout the subclasses of breeding weight within age. On the other hand no trend was evident throughout the major classes of age or the age subclasses within breeding weight. These results were taken to indicate that weight of gilt at breeding exerts a much greater influence on litter performance than does age. Because of the limited numbers involved this trend

cannot be considered conclusive. It differs from that reported by Stewart (25) in which age was shown to be considerably more important than weight as a factor influencing gilt performance.

TABLE 11 - The influence of age at farrow and breeding weight on litter numbers from gilts.

Major class	Major class code	Major class sub-division	No. of Litters	Total No. born	No. born alive	No. weaned	Total No. born	No. born alive	No. Weaned
Age (mo.)	m_{11}		28	9.17	9.03	7.13			
		w_1	14				8.29	8.29	5.86
		w_2	14				9.93	9.64	8.21
	m_{12}		52	8.86	8.61	6.77			
		w_1	26				8.62	8.27	6.35
		w_2	26				9.12	8.96	7.19
	m_{13}		20	9.20	8.80	6.95			
		w_1	10				8.50	8.30	6.30
		w_2	10				9.12	9.30	7.60
Breeding weight (lb.)	bw_1		33	8.36	8.18	6.09			
		m_{11}	11				8.73	8.73	6.00
		m_{12}	17				8.41	8.18	6.29
		m_{13}	5				7.40	7.00	5.60
	bw_2		33	8.85	8.71	7.09			
		m_{11}	9				8.50	8.40	7.20
		m_{12}	20				8.75	8.55	7.00
		m_{13}	4				10.25	10.25	7.25
	bw_3		34	10.09	9.47	7.53			
		m_{11}	8				10.06	10.25	8.62
		m_{12}	15				9.53	9.27	7.00
		m_{13}	11				9.64	9.18	7.45

6. APPLICATION

This study has evaluated the relationship of year and season of birth, breeding weight of the dam and her weight loss during lactation with the performance of the litter. The results have shown litter performance to be conditioned by or related to each of these four factors and have a direct application particularly in nutritional and breeding experiments which deal with productivity of the sow.

Yearly differences for all traits were shown to be large and unpredictable. Seasonal differences were unimportant except for size of litter at weaning with fall litters weaning, on the average, .78 more pigs than spring litters. From these results it is concluded that direct comparisons between litters may be made only for those born within the same season and the same year. If intra-season or intra-year comparisons are desired, statistical corrections must be made to the data.

Weight change of the sow during lactation was closely associated with litter performance. However, the importance of lactation weight change as a measure of productivity is not clear since size of litter itself may be a factor conditioning weight loss during lactation.

Breeding weight of the sow contributed materially to variation in litter numbers and weights at birth and weaning, indicating that corrections are necessary to provide unbiased comparisons between sows of different breeding weights. Correction factors for adjustment of data are given in table 9. For example to provide an unbiased comparison of litters from sows in classes

b_1 and b_2 an adjustment of .94 is necessary for total litter size at birth, of 1.09 for litter size living at birth and .85 for weaned litter size.

Application of these correction factors must be tempered by recognition of the possible genetic interrelationship between weight of sow at a given age and the performance of her litter. This study has considered weight of sow at breeding as an environmental character, while actually it is conditioned in part by the genetic constitution of the sow. However, it is not considered that the genetic component of breeding weight will alter appreciably the interpretation of results. Much of the variation in breeding weight is conditioned by environment. Furthermore the maternal environment provided for the litter is a function of her breeding weight.

A preliminary study was made on the relative influence of age and weight at breeding on first litter size at birth and weaning. Of these two factors, breeding weight exerted the greatest influence. The data were too limited to justify the development of correction factors. However, the results obtained were of sufficient interest to warrant a more detailed study of this question on a larger volume of data.

7. SUMMARY

The redords of 616 Yorkshire litters farrowed over a 20 year period in the University of Alberta's herd were studied to evaluate the relationship between certain traits of the sow and litter performance. Environmental traits of the sow available were breeding weight, age at farrowing, litter order, gestation length and weight changes during gestation and lactation. External environmental influences included year and season. Litter performance traits included litter sizes and weight and average pig weights at birth and weaning.

The data were classified by years, season of farrow (spring or fall), nine classes of breeding weight (40 pound intervals), seven classes of age (six month intervals), eight classes of each of gestation and lactation weight change (20 pound intervals) and nine classes of gestation length (one day intervals).

The correlations of breeding weight with litter order and age at farrowing were .76 and .79 respectively, while the correlation between the latter two was .96. These traits of the sow were associated in a similar manner with litter performance. Of the three, breeding weight appeared to be most decisive in its effect.

Gestation weight change was negatively correlated with breeding weight and lactation weight changes ($r = -.38$ and $-.42$ respectively) but was a class with which litter performance was not associated.

Litter performance was not associated with gestation length which in turn was not correlated with any other sow classes.

Of the environmental factors considered, breeding weight, lactation weight change, year, and season appeared to be those that contributed materially to variations in litter performance independently of each other. The method of least squares was used to obtain a measure of their effects and importance. The model chosen was represented by

$$Y_{ijklm} = \mu + y_i + s_j + b_k + la_l + e_{ijkl}$$

where Y_{ijklm} is a record of the m^{th} litter born in the i^{th} year during the j^{th} season to a dam of the k^{th} breeding weight class and l^{th} weight change during nursing class, μ is an overall mean effect and e_{ijkl} an error effect peculiar to each observation.

The least square parameters indicated:

1. An annual trend characterized by a lower level of weaning performance in terms of litter size, average pig weights and total litter weights during the second half of the period considered.
2. A seasonal difference of .78 more pigs weaned from fall litters.
3. Maximum litter size at birth was obtained for sows weighing from 451 to 490 pounds at breeding. When breeding weights were greater than this a moderate decline occured in litter size. Differences were most important when breeding weight was less than 370 pounds in the case of numbers alive at birth, and less than 410 pounds in the case of total litter size at birth. Differences in litter weights at birth followed a pattern similar to that exhibited by litter size at birth.
4. The number of pigs weaned was relatively constant for sows weighing between 250 and 550 pounds at breeding but declined sharply when breeding weight was outside this range.

5. Litter weaning weight increased progressively as breeding weight of the sow increased to 370 pounds. After this weight the variation present largely reflected differences in weaned litter sizes. Important differences occurred between the same classes in which differences in weaned litter size were large.

6. Increases in weaned litter size and litter weaning weights were closely associated with increases in loss of weight of the sow during nursing.

A preliminary examination indicated that the weight of a gilt at breeding is more important than age as a factor influencing first litter size.

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